EFFECTS OF HEAT AND BRUSH BURNING ON THE PHYSICAL PROPERTIES OF CERTAIN UPLAND SOILS THAT INFLUENCE INFILTRATION

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Hydrologic studies on effect of brush removal from foothill range lands raise the question of the influence of fire and resulting ash on the infiltration capacity of the soil, an influence which may be extremely important since runoff and erosion characteristics of foothill watersheds are directly related to ability of the soils to absorb water. Investigators vary widely on the effect of burning and ash on the surface. In an earlier paper (2) the present writers reported field and laboratory work which indicated that the burning of brush, and the presence of ash resulting from the burning of high concentrations of brush, did not decrease the infiltration capacity of certain upland soils. To determine what influence fire or heat alone may have on infiltration rates, and some of the physical properties of soils that control infiltration, was the purpose of the present study.

LITERATURE REVIEW

Martin and Aldrich (6) reported that although heating soils in a steam treatment increased aggregation of the $<50\mu$ particles of three different soil types, the aggregation decreased with time. In a study of certain so-called "black cotton soils" Screenvisan and Aurangabadkar (9) showed that fire-heating resulted in a marked improvement in soil colloid physical texture and degree of aggregation, and that overheating somewhat improves structure but has no appreciable effect on texture. A number of other workers (1, 4, 5, 7, 10) reported that heating to high temperatures tends to destroy the colloidal properties of soil. There appears to be a range of temperatures in which this change may take place.

Very little data is available on maximum temperature and time duration of heat in burning of brush on rangeland watersheds. Maximum temperatures of 410°F. at a depth of ½ inch during fires in Chaparral brush was reported by Sampson (8). Heyward (3), in a study of soil changes associated with forest fires in stands of pine trees and underlying trash, stated that temperatures in excess of 212°F. at a depth of ½ inch are infrequent. Results[1] from a number of field measurements of temperature at a depth of ⅛ to ¼ inch during typical control burns showed that under standing brush 200°C. was exceeded; under dense brush which had been crushed prior to burning, 400°C. was approached in the ⅛- to ¼-inch layer of soil. Intensity and duration of heat depend, obviously, on a number of factors, among which are: type, density, and dryness of brush; whether brush is standing or crushed; and weather conditions preceding and during the fire.

[1] V. H. Scott. Unpublished data, 1954.

MATERIALS AND PROCEDURE

To establish values for maximum temperature and duration of heat during natural fire conditions, a survey was made of the density of typical ceanothus- and chamise-covered lands. An average field density measured 20 tons of dry material per acre, but maximum densities measured as much as 111 tons per acre. To simulate conditions that might be approached under maximum brush densities, therefore, measurements were made of the heat created by this maximum density. Figure 1 shows the temperature measured at a depth of 1/16 to 1/8 inch below the soil surface for the burning of brush at a rate of 111 tons per acre; the time duration of certain temperatures is also indicated.

In this study of heat effects, two typical upland soils, Hugo and Aiken, were used. These soils are found in a large part of the 10 million acres of brush land in California. Both are slightly acid and were developed in place from weathering of the parent material. The parent material for Hugo was mainly shale, and for Aiken, basic igneous rocks.

Samples of these soils, taken from the top 6 inches in the field, were air-dried and sieved through a 2-mm. screen. The soil was carefully packed into 4-inch-diameter metal cans to a depth of 5 inches. A calibration run of 6 hours was made to determine the infiltration capacity of the column prior to treatments. A constant head of 1 inch of water was maintained on the soil surface, and the leachate was caught volumetrically at the bottom of the soil column for each hourly period. Unless otherwise stated, a constant head was maintained for all infiltration and percolation tests reported. Following a 10-day, air-drying period, 8 replicates were designated as controls and 8 as treated. A minimum of 8 replications was employed throughout the tests reported. Data for Hugo soil (fig. 2) shows the typical results which were obtained and the significant differ-

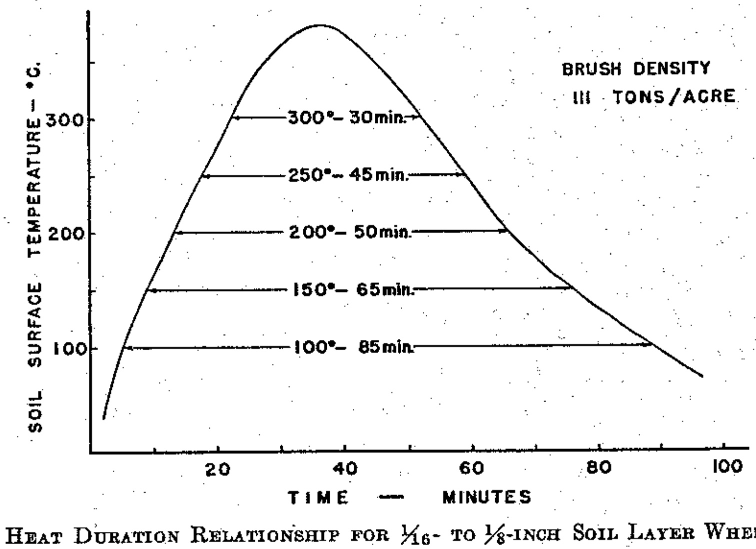

FIG. 1. HEAT DURATION RELATIONSHIP FOR 1/16- TO 1/8-INCH SOIL LAYER WHEN BRUSH BURNED AT 111 TONS PER ACRE

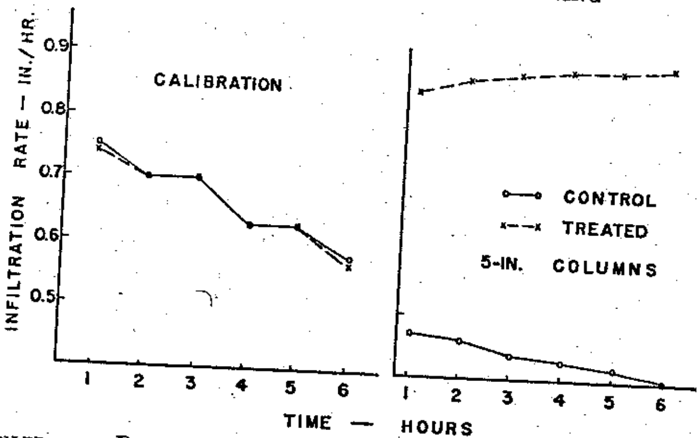

FIG. 2. INFILTRATION RATES FOR HUGO SOIL BEFORE AND AFTER BURNING 110 TONS OF BRUSH PER ACRE

ence in infiltration following the burning of brush on the surface of the treated soil columns. Similar results were obtained with Aiken soil although the difference was not so pronounced.

To determine water stable aggregates the procedure developed by Tiulin (11) and Yoder (12) was followed except that samples were wetted in air rather than in a vacuum prior to submersion in the water bath. Wetting in air was considered to approach more closely the manner by which the soil is wetted in the laboratory and field during the infiltration process; with preliminary wetting in a vacuum the total percentage of the sample retained on the sieve was higher than in samples wetted in air.

RESULTS AND DISCUSSION

The first series of experiments were designed to compare the effect of heat on 1½-inch-diameter soil columns 3¼ inches high in respect to the influence of this heat on percolation of water through the column and changes in soil particle aggregation. Treated columns were heated in an oven at various temperatures for various time periods (fig. 1.), namely: 100°C., 85 minutes; 150°C., 65 minutes; 200°C., 50 minutes; 250°C., 45 minutes; and 300°C., 30 minutes. These time intervals permitted the major part of the soil mass to reach the temperatures indicated.

The following measurements were then made on control and treated columns: (*a*) time required for water to percolate through the dry soil column, that is, designated percolation time; (*b*) infiltration rate for a 3-hour period; and (*c*) water stable aggregate analysis of the entire soil column.

Results for percolation time and infiltration rates for Hugo and Aiken soils are presented in table 1. The percolation time of Hugo soil for temperatures over 200°C. was approximately half that of the control; for Aiken soil there appears to be no correlation with temperature. The infiltration rate of Hugo soil was significantly higher for all temperatures; at 250°C. the rate was twice that of the control. Again data for Aiken failed to indicate a correlation.

TABLE 1

Percolation time and infiltration rates of control and differentially heated Hugo and Aiken soil

Temperature and Time Heated		Percolation Time		Infiltration Rate			
		Hugo	Aiken	Hugo	Aiken	Variance from Control	
						Hugo	Aiken
°C.	min.	min.	min.	in./hr.	in./hr.	in./hr.	in./hr.
Control		55	47	0.81	0.91		
100	90	55	—	0.91	—	0.10	—
150	65	30	—	1.18	—	0.37	—
200	50	30	54	1.35	0.80	0.54	−0.10
250	45	28	65	1.62	0.91	0.81	0.0
300	30	26	45	1.72	0.91	0.91	0.0

TABLE 2

Water stable aggregate analysis of Hugo soil after heat treated and an infiltration run

Temperature and Time Heated		Soil Retained, by Size of Sieve Mesh Opening					
		10	20	40	60	140	Total
°C	min.	%	%	%	%	%	%
Control		0.0	9.6	12.2	7.9	14.1	43.8
100	85	0.3	11.8	16.5	11.2	19.0	58.9
150	65	0.3	11.4	15.5	9.8	18.7	55.8
200	50	0.3	12.5	16.2	10.5	18.6	58.2
250	45	0.4	9.9	12.7	8.9	18.7	50.7
300	30	0.4	10.4	12.8	8.9	18.6	51.1
After 3-hour infiltration run							
Control		0.3	8.4	9.7	6.6	16.7	41.7
100	85	0.2	8.6	10.6	7.0	17.2	43.7
150	65	0.2	8.4	10.1	6.9	16.1	41.7
200	50	0.2	8.5	9.8	7.0	14.7	40.3
250	45	0.3	8.0	9.2	6.4	14.9	38.8
300	30	0.2	7.6	9.5	6.0	14.0	38.3

An aggregate analysis of control, heat-treated, and heat-treated followed by infiltration run for Hugo soil is given in table 2. From a comparison of the control and all heat-treated samples, it is evident that the per cent of soil retained was increased in every screen size and for every temperature. Heating the entire soil column apparently did materially affect the aggregation of the dry soil. The same comparison after water had percolated through these soils for 3 hours, however, shows the heated columns had no increase in aggregate size for the screens used. In fact, for the higher temperatures the percentages retained on the smaller screens and the totals for those screens are lower than those of the controls. That the soil column was subjected to an additional wetting and drying cycle may explain this result, but it should also be noted that aggregation of

TABLE 3

Water stable aggregate analysis of Aiken soil after heat treated and an infiltration run

Temperature and Time Heated		Soil Retained, by Size of Sieve Mesh Opening					
		10	20	40	60	140	Total
°C.	*min.*	%	%	%	%	%	%
Control		0.4	14.5	21.7	13.3	17.4	67.4
100	85	0.2	12.7	21.5	13.7	19.1	67.3
150	65	0.3	13.5	21.7	14.1	19.0	68.6
200	50	0.3	13.3	23.0	14.1	17.7	68.4
250	45	0.3	12.5	22.2	15.0	19.7	69.7
300	30	0.2	14.2	24.0	15.1	18.3	71.9
After 3-hour infiltration run							
Control		0.4	10.9	18.3	12.0	16.0	57.7
200	50	0.6	10.8	17.9	11.8	15.4	56.5
250	45	0.7	9.9	17.1	11.5	15.8	55.1
300	30	0.8	10.5	17.8	11.9	16.2	57.2

soil particles may have occurred in the size range below those measured in these tests. This latter point requires further investigation.

The results for similar treatments of Aiken soil are presented in table 3. Except for the 100°C. heat, the percentages of the treated columns are greater, in comparison to the control, in the three smaller sizes and less in the larger sizes. Total percentages for the treatments are higher than the control except for the 100°C. heat.

After an infiltration run, the total percentage retained of both the control and treated columns is much less than before wetting. With this general decrease is an increase in the percentage of larger-sized particles, that is, an increase in the amount retained on the number 10 screen.

The next series of tests, made on 4-inch-diameter dry Hugo soil columns 5 inches high, was designed to test the effect of heat applied directly to the soil surface by means of electric coils. Intensity and duration of heat applied followed the curve shown in figure 1 for the burning brush at 111 tons per acre on the soil surface. After heating, the soil surface had a slight reddish tint and appeared to have more large-sized soil aggregates on the surface than did the control.

A percolation time test was made on the control and treated columns. The time required for the control columns was 31 minutes and for the treated only 22 minutes. A comparison of the infiltration rates of the control and treated columns for a 3-hour run is presented in figure 3. The surface-heat-treated columns had a much higher infiltration rate.

These experiments indicated that heat was producing a change in aggregation which contributed to a significant increase in infiltration, but whether this advantage would be maintained if water were applied to the surface of the cylinders other than by ponding remained a question. In the next series of tests

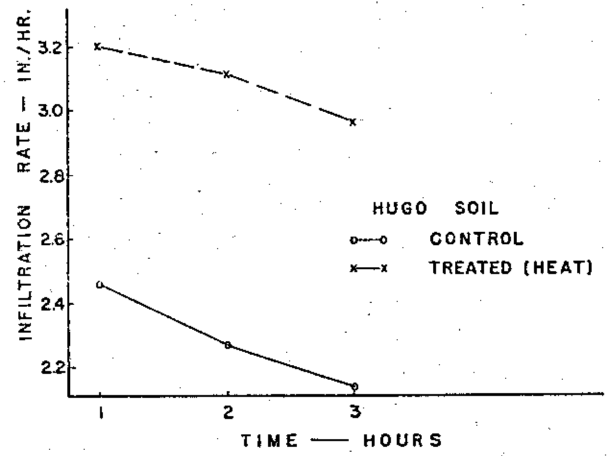

FIG. 3. INFILTRATION RATES FOR CONTROL AND SURFACE-TREATED HUGO SOIL

on Hugo soil, therefore, the cylinders were packed with soil to the top edge of the cylinder and heated to 250° and 300°C. for 45 and 30 minutes, respectively.

Instead of ponding water on the surface as in the previous tests, water was applied uniformly over the control and treated columns by means of a simulated rainfall applicator which discharged water in fine drops. The columns were prewetted and a test begun with water applied at a rate of 4 inches per hour—which was much in excess of the infiltration rate of the soil. Although water which did not enter the soil column ran off the surface, it did not create a ponded water surface condition. Infiltration rates of the treated columns were 0.14 and 0.22 inch per hour higher than the controls for the 250° and 300°C. temperatures, respectively.

To locate the depth at which changes in aggregation and permeability were occurring because of brush burning on the soil surface, a series of hydraulic head measurements were made on 5-inch and 16-inch soil columns. Manometers were inserted into the sides of the metal cylinders at 1- and 4-centimeter intervals, respectively, on the 5- and 16-inch cylinders. From the differences in hydraulic head recorded between adjacent manometers and the average velocity of the water passing through the cross-sectional area, the permeability coefficient, K, in Darcy's equation was calculated.

Calculated values of the permeability coefficients by depths for Hugo and Aiken soils are given in table 4. For the 5-inch Hugo columns, treated values are significantly higher than controls down to a depth of 4 cm. Below the 4-cm. level permeability was only slightly higher in the treated column. Average overall permeability is much higher for the treated column as it would be expected to be since the average infiltration rate was 1.12 inches per hour compared to 0.76 inch per hour for the controls.

In the 16-inch Hugo columns there is apparently no significant difference at the levels measured even though the overall permeability coefficient and infiltration rate of the treated columns were considerably higher. On the 16-inch

TABLE 4

Calculated permeability coefficients (K) *by depths for Hugo and Aiken soil*

Depth	Hugo Soil		Aiken Soil	
	Control	Treated	Control	Treated
	5-inch soil columns			
cm.	*cc./hr.*		*cc./hr.*	
1–2	52	140	98	96
2–3	68	138	46	62
3–4	86	157	108	111
4–5	161	159	123	123
5–6	136	156	145	136
6–7	105	138	87	147
7–8	109	155	167	182
8–9	151	172	148	191
9–10	108	158	107	183
	Overall K			
	64	101	93	114
	16-inch soil columns			
2–6	283	232	257	173
6–10	77	140	180	214
10–14	108	112	186	160
14–18	64	115	142	188
18–22	160	165	96	187
22–26	233	203	158	125
	Overall K			
	159	194	167	171

columns the 4-cm. manometer spacing appears not to be sufficiently close to detect the changes in hydraulic head that the 1 cm.-spaced manometers on the 5-inch columns indicated.

Permeability coefficients of the surface layers in Aiken soil were only slightly higher in the treated columns. Similarly the overall permeability coefficient and infiltration rate of the treated columns are only slightly higher than those of the controls.

To check the aggregation gradation by depth, a test was made to compare water stable aggregates in control and treated columns which were subjected to an infiltration run with water applied by the simulated rainfall mentioned. Results of this test are presented in table 5. A marked difference in aggregation appears in the 0- to ¼-inch level, but for succeeding layers values appear to be approximately equal to the control. This evidence tends to support the data of the permeability measurements and calculations in that the major physical change which influences the permeability and thus the transmissibility of water through the column is an increase in aggregation within the uppermost layer of

TABLE 5

Water stable aggregate analysis of Hugo soil after water applied as simulated rainfall

Sieve Size—Mesh Opening	Soil Retained					
	0–¼ in. Depth		¼–½ in. Depth		½–1 in. Depth	
	Control	Treated	Control	Treated	Control	Treated
	%	%	%	%	%	%
10	0.1	2.1	0.2	0.3	0.3	0.2
20	10.1	15.6	12.1	10.0	11.9	12.8
40	11.9	21.5	13.5	13.8	14.3	13.9
60	6.9	10.1	7.3	9.2	7.6	7.7
140	13.8	15.8	11.4	14.3	11.6	12.2
Total	*42.8*	*64.8*	*44.6*	*47.6*	*45.2*	*46.8*

soil. On the basis of these studies heat effects and the resulting physical changes which occur in the soil are apparently independent of the method of water application.

SUMMARY

The results reported indicate that heat and burning brush on Hugo soil have resulted in measurable changes in aggregation and permeability in the surface layers. These changes produce appreciable increases in the infiltration rates. On Aiken soil these effects are not so pronounced.

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